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Acoustic Change Detection Using Sources of Opportunity

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ARL-TN-0454   **September 2011**

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Army Research Laboratory

Adelphi, MD 20783-1197

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REPORT DOCUMENTATION PAGE

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED (From - To)
September 2011	Final	

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Acoustic Change Detection Using Sources of Opportunity	
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)	5d. PROJECT NUMBER
Owen R. Wolfe and Geoffrey H. Goldman	
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
U.S. Army Research Laboratory ATTN: RDRL-SES-P 2800 Powder Mill Road Adelphi, MD 20783-1197	ARL-TN-0454

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

There is interest in developing low-cost, low-power non-line-of-sight sensors for monitoring human activity. This report describes an algorithm that can detect a physical change in a building such as a door opening or closing. The algorithm is based on cross-correlating the acoustic signal measured from two microphones. Detection occurs when a statistically significant change in normalized cross-correlation is measured at different times. The algorithm was tested with an experiment that used a simple, inexpensive, hand-held FM radio as a sound source, two microphones, and a data acquisition system. The algorithm successfully detected a change in the environment when a door was opened or closed.

15. SUBJECT TERMS

Acoustic, change detection, sources of opportunity

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Geoffrey Goldman
a. REPORT	b. ABSTRACT	c. THIS PAGE	UU	18	19b. TELEPHONE NUMBER *(Include area code)* (301) 394-0882
Unclassified	Unclassified	Unclassified			

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Acknowledgments

We would like to thank Chris Reiff and Gary Chatters for their help with the experiment.

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1. Introduction

There is interest in developing non-line-of-sight sensors for monitoring human activity. While individuals performing activities can intentionally or unintentionally reduce their signature to sensors such as microphones and cameras, they may generate other clues that can be exploited. Active acoustics can be used to perform change detection inside buildings. Common challenges with active acoustics systems are audible range frequencies giving away the position of the system and ultrasound frequencies quickly attenuating with range (1 dB/m) (*1*). In order to avoid these issues, we use an acoustic source of opportunity such as a radio, a conversation, or another similar signal. This mitigates the problem of the source being discovered and reduces the cost of the system (*2, 3*).

Change detection is the process of using data from sensors to measure a change in the surrounding area at different times. Change detection is accomplished by subtracting a reference image or profile of an area from a test image (*4*). Any changes in the scene are noticed, while things that stayed the same are cancelled. An acoustic change detection algorithm requires an image or profile of the environment. A relatively simple way of generating an acoustic profile of an area is to cross-correlate the data measured on two microphones (*5*). For discrete signals, cross-correlation is defined as

$$R_{xy}(m) = \sum_{m=-\infty}^{\infty} x(n)y(m+n),$$

(1)

where x*(n)* is the measured signal from microphone 1 at index *n* and *y(m+n)* is the measured signal from microphone 2 at time *(m+n)*. With the addition of a third microphone, acoustic imagery could be generated and allow for localization in a plane.

2. Experiment

The algorithm was tested with a simple experiment. Two microphones were placed 4 m apart. The acoustic source was an FM radio that was placed less than a 1 m away from the first microphone. The radio was set to a station that played music and talk. Data from the microphones were recorded at a sampling rate of 10 KHz with the door position either opened or closed (figure 1). The data collected during different trials were used to evaluate the algorithm.
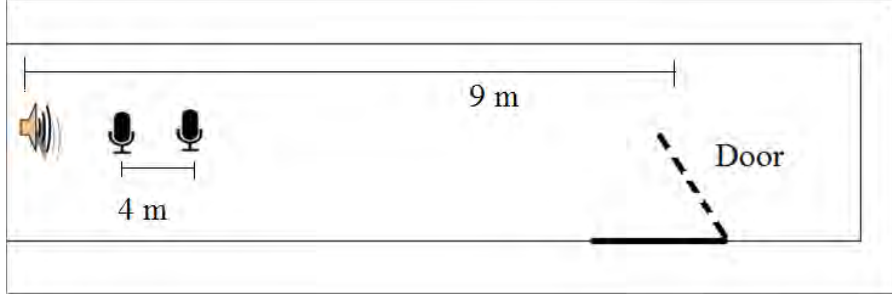
Figure 1. A schematic of the experiment.

3. Algorithm

The algorithm begins by filtering low frequency noise using a Butterworth filter. Next, the data sets from microphones 1 and 2 are split and delayed by approximately 40 s. This ensures that the data are only from periods where the door was completely open or completely closed.

The channels are equalized by first converting the data into the frequency domain (figure 2) using a fast Fourier transform (FFT). The amplitude of the two spectrums are equalized to

$$S(w) = \min\left(\left|X_1(\omega)\right|, \left|X_2(\omega)\right|\right), \tag{2}$$

where $X_1(\omega)$ and $X_2(\omega)$ are the discrete Fourier transforms of the data on microphones 1 and 2, ω is frequency, and *min* is minimum of the amplitude of the two spectrums for each frequency. To equalize the spectrums, the original spectrums are divided by their own magnitudes and then multiplied by the magnitude of the $S(w)$. Then, the signals are converted back to the time domain using an inverse fast Fourier transform (iFFT). These new time domain signals are now equalized. Next the data are cross-correlated. The outputs of the cross-correlations are subtracted and normalized using

$$D(n) = \frac{\left|R_{x_1 y_1}(n) - R_{x_2 y_2}(n)\right|}{\left(\left|R_{x_1 y_1}(n)\right| + \left|R_{x_2 y_2}(n)\right| + \sigma\right)_0} \left(\frac{r(n)\left|r(n) - r_0\right|}{2} + 1\right)^{\frac{1}{4}}, \tag{3}$$

where $R_{x1y1}(n)$ is the first cross-correlation at index n and $R_{x2y2}(n)$ is the second cross-correlation at index n, and $r(n)$ corresponds approximately to the range and is given by

$$r(n) = cnT + r_1, \tag{4}$$

where n is the index, c is the speed of sound, T is one over the sampling rate, and r_1 is the distance between the source and the first microphone. This normalization partially accounts for the attenuation of the signal with range. Next, the sum is compared to a threshold based upon a Student's *t*-distribution.
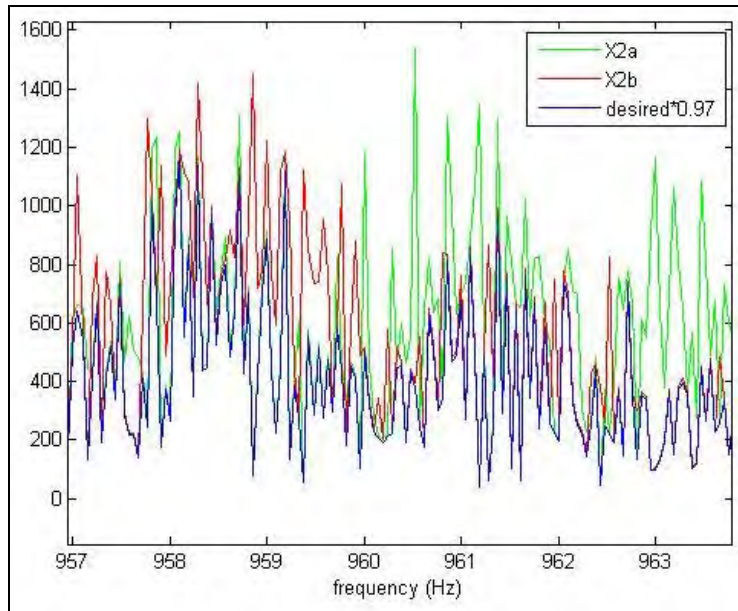
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Figure 2. A portion of the frequency domain data (red and green) with
the desired spectrum (blue).
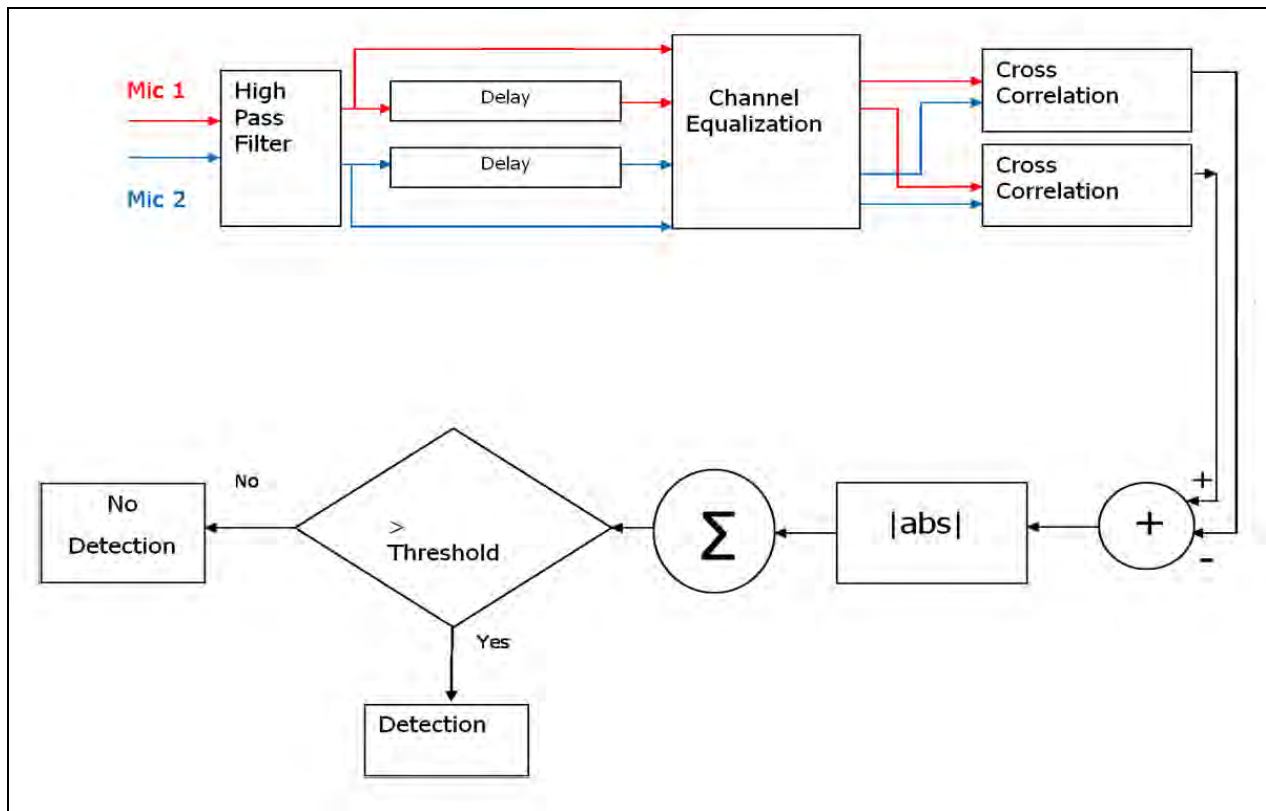
Figure 3 shows a block diagram of the algorithm.

Figure 3. A block diagram of the algorithm.

4. Processing

Results are shown for data collected during two different trials. First, the data are equalized using equation 2. Figure 4 shows the waveforms in time when the door was opened and figure 5 shows the waveforms in a time when the door remained closed.
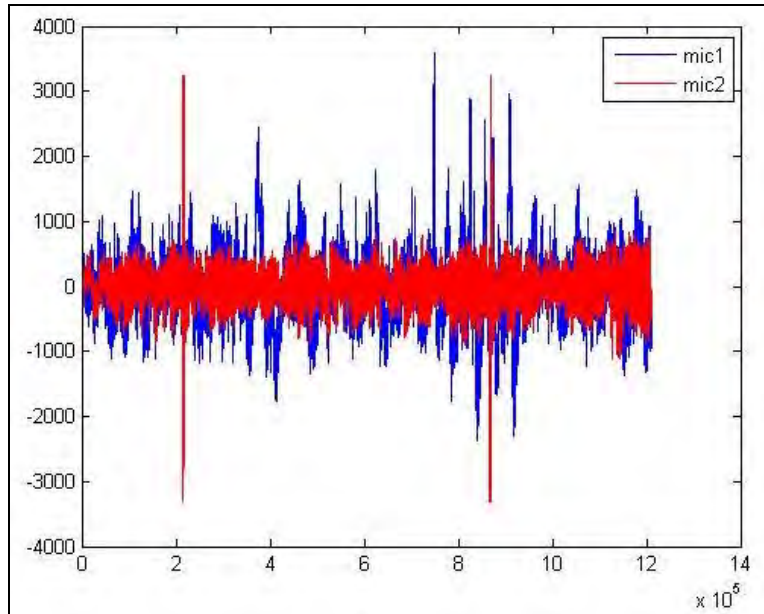

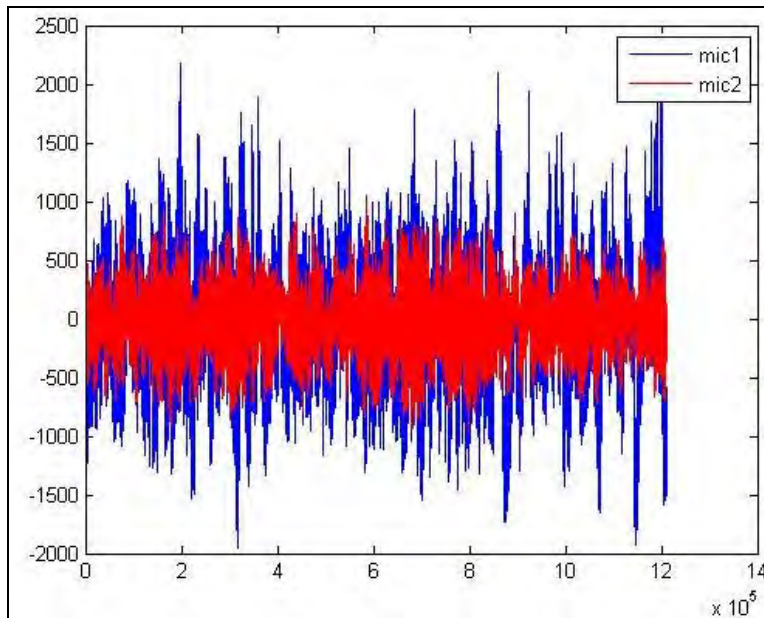Figure 4. Acoustic data from a trial during which the door was opened.

Figure 5. Acoustic data from a trial during which the door remained closed,

4

Next, the results from figures 4 and 5 are cross-correlated. The results are shown in figures 6–9. Figures 8–9 are zoomed-in versions of the data in figures 6–7. The *x*-axis has been converted to range by multiplying the time variable in the cross correlation by the speed of sound. The large peak in the figures occurs at 4.5 m, which correspond to the distance between the microphones.
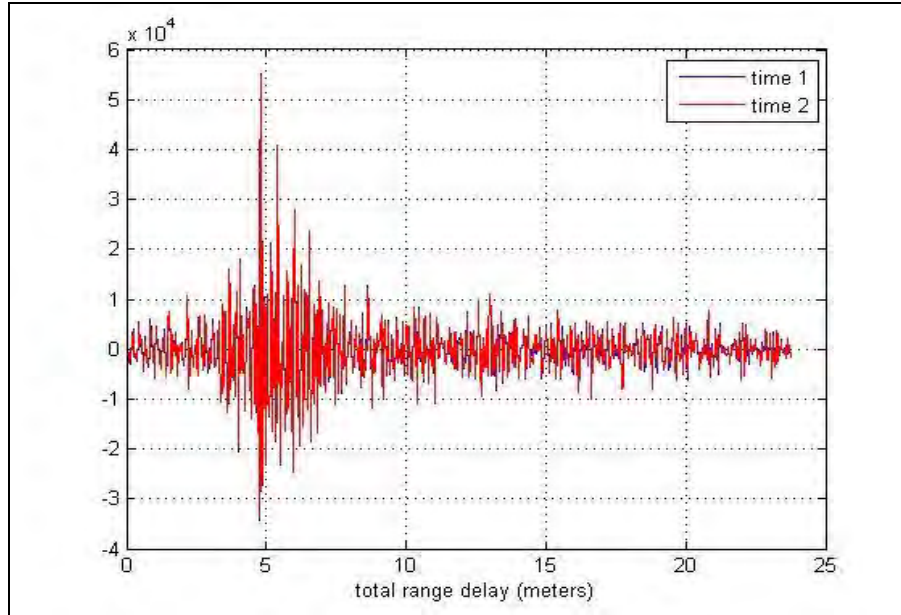

Figure 6. The cross-correlations of data from a trial during which the door was opened.
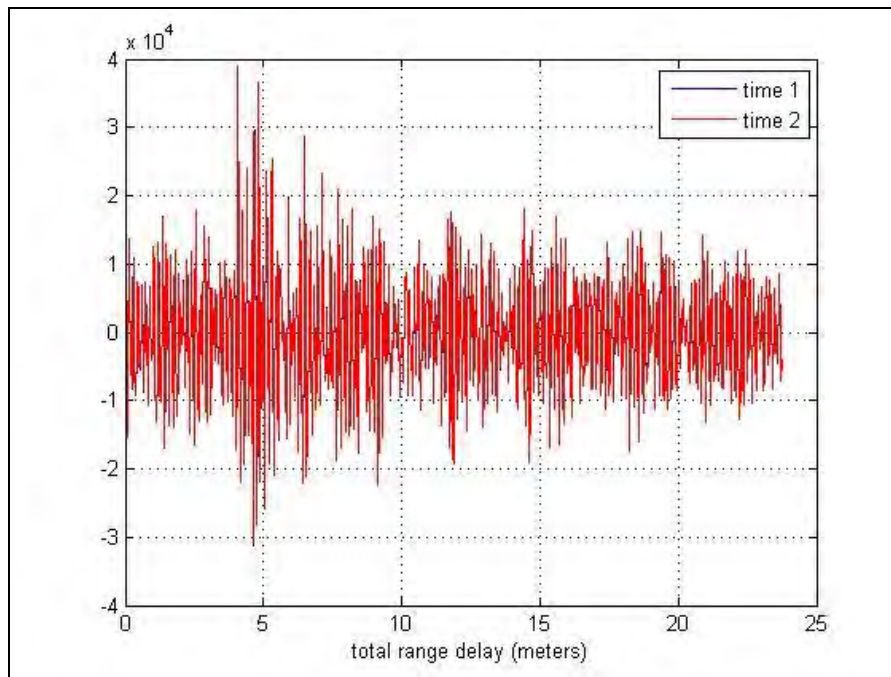

Figure 7. Cross-correlations of data from a trial during which the door remained closed.
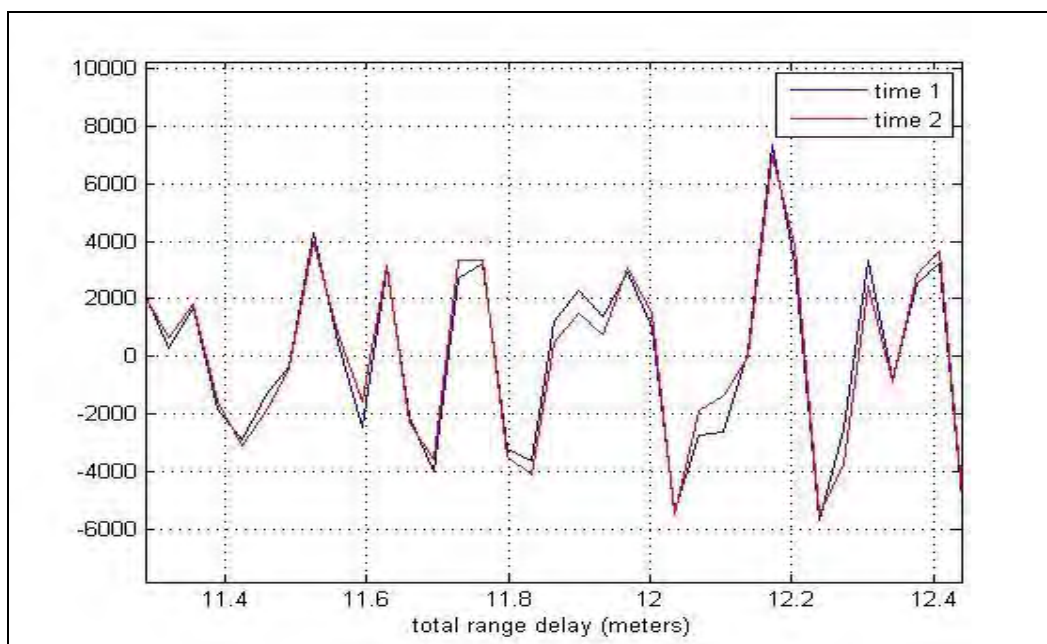
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Figure 8. The cross-correlations from the trial where the door was open at time 1 and closed at time 2.
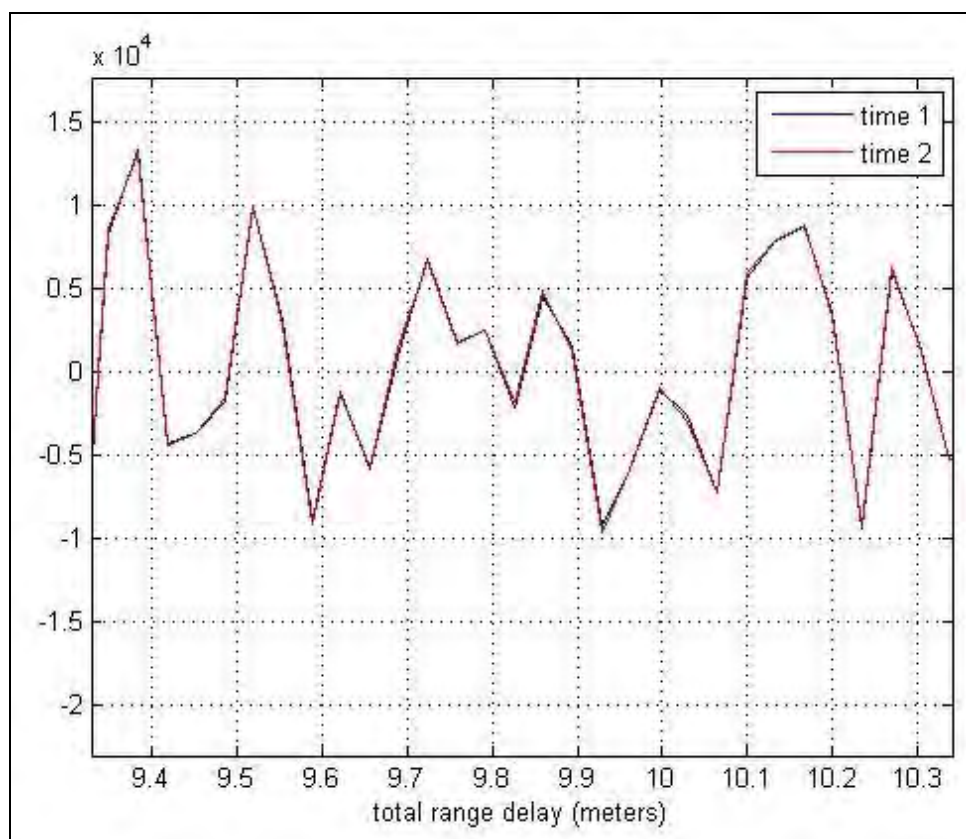
Figure 9. The cross-correlation from a trial where the door remained shut at time 1 and time 2.

6

Lastly, the cross-correlations are subtracted from each other, normalized, and then summed. Figure 10 shows the results for the door being opened then closed, while figure 11 shows the results for the door being shut at both times.

Figure 10. The difference of the cross-correlations from a trial where the door was opened has a sum of 218.

Figure 11. The difference of the cross-correlations from a trial during in which the door remained closed has a sum of 44.

5. Discussion

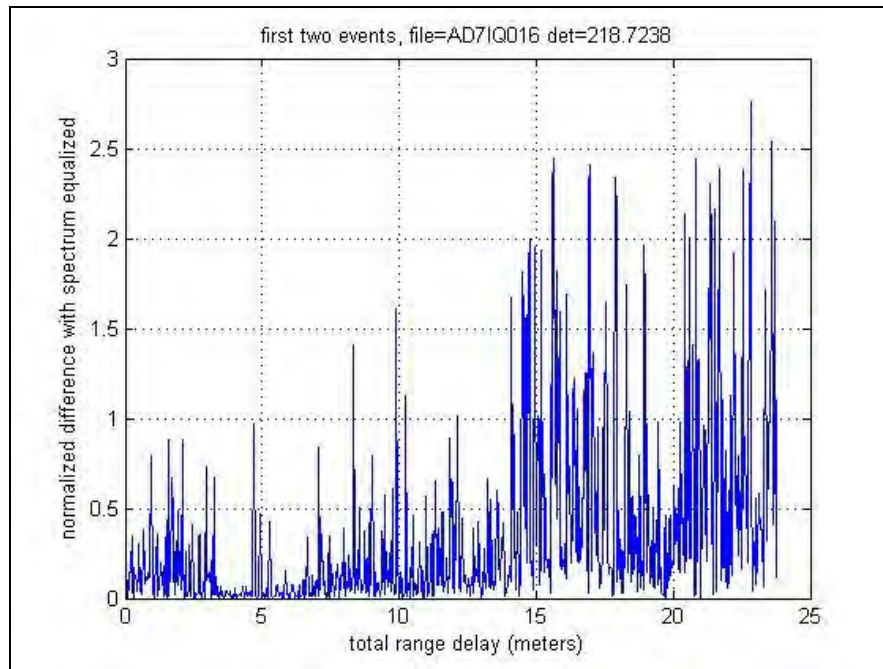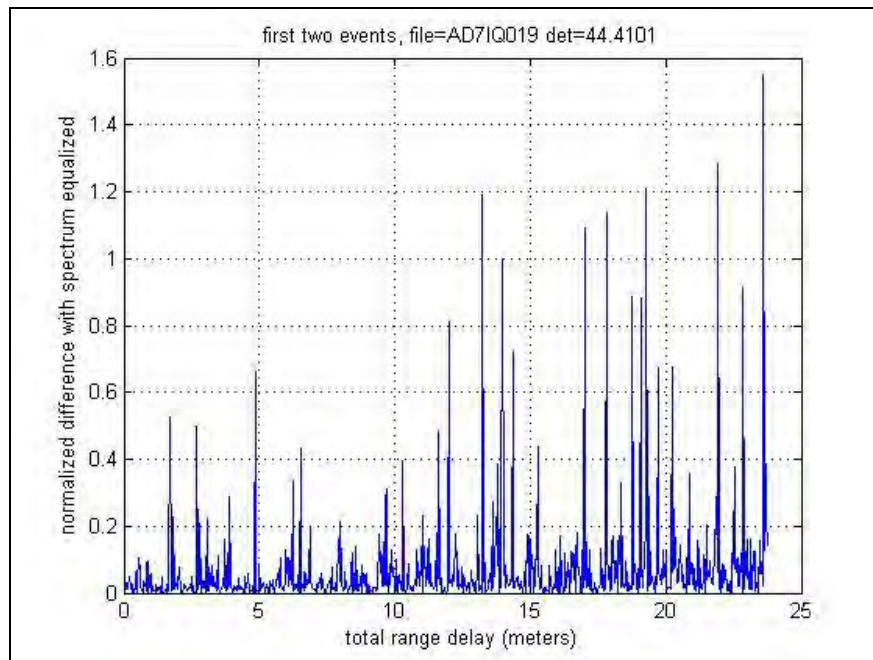The results show that the sum of the differences in the amplitude of the cross-correlated signal received when the door position changed is greater than with no change. This is the result of the change in the scattering of the acoustic energy caused by the door opening. Statistics were calculated on the average normalized differences between the cross-correlation results with no change in the environment using the four data sets. The mean was 28 and the standard deviation was 38. The sum of the data when the environment was changed was 218. This is greater than four standard deviations away from the mean results when the environment remained constant. These results were evaluated using a Student's *t*-test, which indicated that there was greater than a 99.9% confidence that a change occurred.

6. Conclusion

These results demonstrate acoustic change detection using sources of opportunity. The simplicity of this technique means that acoustic surveillance could be conducted using inexpensive and nearly unnoticeable equipment.

Ideally, the range to the change could be determined, but this algorithm was unable to determine the range because of the noisy cross-correlation results and a complex scattering environment. A more complex algorithm is required to obtain reliable range information.

7. References

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